(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
13 November 2003 (13.11.2003)

PCT

(10) International Publication Number
WO 03/093499 A2

(51) International Patent Classification[7]: C12Q 1/44, G01N 33/94, C12Q 1/68, G01N 33/68

(21) International Application Number: PCT/IB03/01684

(22) International Filing Date: 22 April 2003 (22.04.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10/139,183 3 May 2002 (03.05.2002) US
10/177,018 20 June 2002 (20.06.2002) US

(71) Applicant *(for all designated States except US)*: **PFIZER PRODUCTS INC.** [US/US]; Eastern Point Road, Groton, CT 06340 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **LEBEL, Lorraine, Ann** [US/US]; Pfizer Global Research and Development, Eastern Point Road, Groton, CT 06340 (US). **MENNITI, Frank, Samuel** [US/US]; Pfizer Global Research and Development, Eastern Point Road, Groton, CT 06340 (US). **SCHMIDT, Christopher, Joseph** [US/US]; Pfizer Global Research and Development, Eastern Point Road, Groton, CT 06340 (US).

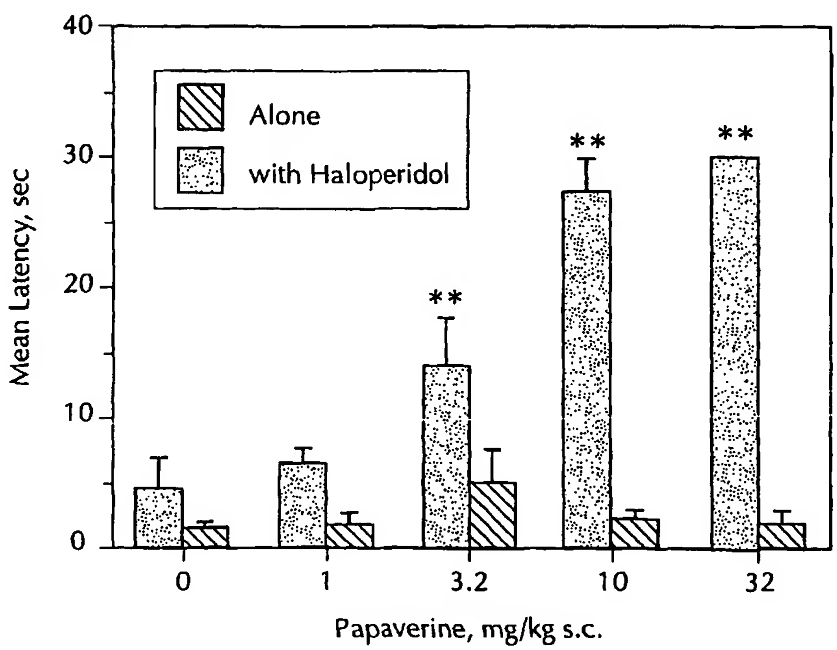
(74) Agent: **LUMB, J., Trevor**; Pfizer Inc., 201 Tabor Road, Morris Plains, NJ 07950 (US).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: THERAPEUTIC USE OF SELECTIVE PDE10 INHIBITORS



(57) Abstract: The invention provides a method for treating certain neurologic and psychiatric disorders in mammals, including humans, comprising administration of a selective PDE10 inhibitor. In particular, the invention relates to treatment of mood, movement, and anxiety disorders; psychosis; drug, for example alcohol, addiction; disorders having as a symptom deficient cognition; and neurodegenerative disorders and conditions. The invention furthermore provides the use of papaverine as a selective inhibitor of PDE10. The invention also provides assays for identifying chemical compounds that have activity as selective PDE10 inhibitors.

WO 03/093499 A2

Published:
— *without international search report and to be republished upon receipt of that report*

THERAPEUTIC USE OF SELECTIVE PDE10 INHIBITORS

Background of the Invention

The subject invention relates to the treatment of disorders of the central nervous system. More particularly, the invention relates to treatment of neurologic and psychiatric disorders, for example psychosis and disorders comprising deficient cognition as a symptom. Furthermore, this invention relates to treatment of neurodegenerative disorders and conditions. This invention also relates to PDE10 inhibition. This invention also relates to assays for identifying chemical compounds that have activity as selective PDE10 inhibitors.

The cyclic nucleotides, cyclic-adenosine monophosphate (cAMP) and cyclic-guanosine monophosphate (cGMP), function as intracellular second messengers regulating a vast array of intracellular processes particularly in neurons of the central nervous system. In neurons, this includes the activation of cAMP and cGMP dependent kinases and subsequent phosphorylation of proteins involved in acute regulation of synaptic transmission as well as in neuronal differentiation and survival. The complexity of cyclic nucleotide signaling is indicated by the molecular diversity of the enzymes involved in the synthesis and degradation of cAMP and cGMP. There are ten families of adenylyl cyclases, two of guanylyl cyclases, and eleven of phosphodiesterases (PDE's). Furthermore, different types of neurons are known to express multiple isozymes of each of these classes and there is good evidence for comparmentalization and specificity of function for different isozymes within a given neuron.

cAMP is synthesized by a family of membrane bound enzymes, the adenylyl cyclases mentioned above. A broad range of serpin family receptors regulates these enzymes through a coupling mechanism mediated by heterotrimeric G-proteins. Increases in intracellular cAMP leads to activation of cAMP-dependent protein kinases, which regulate the activity of other signaling kinases, transcription factors, and enzymes via their phosphorylation. Cyclic-AMP may also directly affect the activity of cyclic nucleotide regulated ion channels, phosphodiesterases, or guanine nucleotide exchange factors. Recent studies also suggest that intracellular cAMP may function as a precursor for the neuromodulator, adenosine, following its transport out of the cell.

Guanylyl cyclase, which synthesizes cGMP, exists in membrane bound and cytoplasmic forms. The membrane bound form is coupled to G-protein linked receptors such as that for ANP (atrial naturetic peptide) whereas soluble guanylyl cyclase is activated by nitric oxide (Wang, X. and Robinson, P. J. Journal of Neurochemistry 68(2):443-456, 1997). Similar to cAMP, downstream mediators of cGMP signaling in the central nervous system include cGMP-gated ion channels, cGMP-regulated phosphodiesterases and cGMP-dependent protein kinases. Given the important role of cyclic nucleotides in signal transduction within the central nervous system, therapeutic benefits may be derived from the use of compounds that affect the regulation of cyclic nucleotide signaling.

A principal mechanism for regulating cyclic nucleotide signaling is by phosphodiesterase-catalyzed cyclic nucleotide catabolism. There are eleven known families of phosphodiesterases (PDEs) encoded by 21 different genes. Each gene typically yields multiple splice variants that further contribute to the isozyme diversity. The PDE families are distinguished functionally based on cyclic nucleotide substrate specificity, mechanism(s) of regulation, and sensitivity to inhibitors. Furthermore, PDEs are differentially expressed throughout the organism, including in the central nervous system. As a result of these distinct enzymatic activities and localization, different PDEs isozymes can serve distinct physiological functions. Furthermore, compounds that can selectively inhibit distinct PDE families or isozymes may offer particular therapeutic effects, fewer side effects, or both.

PDE10 is identified as a unique family based on primary amino acid sequence and distinct enzymatic activity. Homology screening of EST databases revealed mouse PDE10A as the first member of the PDE10 family of phosphodiesterases (Fujishige et al., J. Biol. Chem. 274:18438-18445, 1999; Loughney, K. et al., Gene 234:109-117, 1999). The murine homologue has also been cloned (Soderling, S. et al., Proc. Natl. Acad. Sci. USA 96:7071-7076, 1999) and N-terminal splice variants of both the rat and human genes have been identified (Kotera, J. et al., Biochem. Biophys. Res. Comm. 261:551-557, 1999; Fujishige, K. et al., Eur. J. Biochem. 266:1118-1127, 1999). There is a high degree of homology across species. The mouse PDE10A1 is a 779 amino acid protein that hydrolyzes both cAMP and cGMP to AMP and GMP, respectively. The affinity of PDE10 for cAMP (K_m = 0.05 μM) is higher than for cGMP (K_m = 3 μM). However, the approximately 5-fold greater V_{max} for cGMP over cAMP has lead to the suggestion that PDE10 is a unique cAMP-inhibited cGMPase (Fujishige et al., J. Biol. Chem. 274:18438-18445, 1999).

PDE10 also is uniquely localized in mammals relative to other PDE families. mRNA for PDE10 is highly expressed only in testis and brain (Fujishige, K. et al., Eur J Biochem. 266:1118-1127, 1999; Soderling, S. et al., Proc. Natl. Acad. Sci. 96:7071-7076, 1999; Loughney, K. et al., Gene 234:109-117, 1999). These initial studies indicated that within the brain PDE10 expression is highest in the striatum (caudate and putamen), n. accumbens, and olfactory tubercle. More recently, a detailed analysis has been made of the expression pattern in rodent brain of PDE10 mRNA (Seeger, T.F. et al., Abst. Soc. Neurosci. 26:345.10, 2000) and PDE10 protein (Menniti, F.S., Stick, C.A., Seeger, T.F., and Ryan, A.M., *Immunohistochemical localization of PDE10 in the rat brain*. William Harvey Research Conference 'Phosphodiesterase in Health and Disease', Porto, Portugal, Dec. 5-7, 2001).

Summary of the Invention

The present invention provides a method of treating an anxiety or psychotic disorder in a mammal, including a human, which comprises administering to said mammal an amount of a selective PDE10 inhibitor effective in treating said anxiety or psychotic disorder.

The invention also provides a method of treating an anxiety or psychotic disorder in a mammal, including a human, which comprises administering to said mammal an amount of a selective PDE10 inhibitor effective in inhibiting PDE10.

Examples of psychotic disorders that can be treated according to the present invention include, but are not limited to, schizophrenia, for example of the paranoid, disorganized, catatonic, undifferentiated, or residual type; schizophreniform disorder; schizoaffective disorder, for example of the delusional type or the depressive type; delusional disorder; substance-induced psychotic disorder, for example psychosis induced by alcohol, amphetamine, cannabis, cocaine, hallucinogens, inhalants, opioids, or phencyclidine; personality disorder of the paranoid type; and personality disorder of the schizoid type.

Examples of anxiety disorders that can be treated according to the present invention include, but are not limited to, panic disorder; agoraphobia; a specific phobia; social phobia; obsessive-compulsive disorder; post-traumatic stress disorder; acute stress disorder; and generalized anxiety disorder.

This invention also provides a method of treating a movement disorder selected from Huntington's disease and dyskinesia associated with dopamine agonist therapy in a mammal, including a human, which method comprises administering to said mammal an amount of a selective PDE10 inhibitor effective in treating said disorder.

This invention also provides a method of treating a movement disorder selected from Huntington's disease and dyskinesia associated with dopamine agonist therapy in a mammal, including a human, which method comprises administering to said mammal an amount of a selective PDE10 inhibitor effective in inhibiting PDE10.

This invention further provides a method of treating a movement disorder selected from Parkinson's disease, restless leg syndrome, and essential tremor in a mammal, including a human, comprising administering to said mammal an amount of a selective PDE10 inhibitor effective in treating said disorder.

This invention also provides a method of treating a movement disorder selected from Parkinson's disease, restless leg syndrome, and essential tremor in a mammal, including a human, comprising administering to said mammal an amount of a selective PDE10 inhibitor effective in inhibiting PDE10.

This invention also provides a method of treating a disorder selected from obsessive/compulsive disorders, Tourette's syndrome and other tic disorders in a mammal,

including a human, which method comprises administering to said mammal an amount of a selective PDE10 inhibitor effective in treating said disorder.

This invention also provides a method of treating obsessive/compulsive disorder, Tourette's syndrome and other tic disorders in a mammal, including a human, which method comprises administering to said mammal an amount of a selective PDE10 inhibitor effective in inhibiting PDE10.

This invention further provides a method of treating a drug addiction, for example an alcohol, amphetamine, cocaine, or opiate addiction, in a mammal, including a human, which method comprises administering to said mammal an amount of a selective PDE10 inhibitor effective in treating drug addiction.

This invention also provides a method of treating a drug addiction, for example an alcohol, amphetamine, cocaine, or opiate addiction, in a mammal, including a human, which method comprises administering to said mammal an amount of a selective PDE10 inhibitor effective in inhibiting PDE10.

A "drug addiction", as used herein, means an abnormal desire for a drug and is generally characterized by motivational disturbances such a compulsion to take the desired drug and episodes of intense drug craving.

This invention further provides a method of treating a disorder comprising as a symptom a deficiency in attention and/or cognition in a mammal, including a human, which method comprises administering to said mammal an amount of a selective PDE10 inhibitor effective in treating a deficiency in attention and/or cognition.

This invention also provides a method of treating a disorder comprising as a symptom a deficiency in attention and/or cognition in a mammal, including a human, which method comprises administering to said mammal an amount of a selective PDE10 inhibitor effective in inhibiting PDE10.

The phrase "deficiency in attention and/or cognition" as used herein in "disorder comprising as a symptom a deficiency in attention and/or cognition" refers to a subnormal functioning in one or more cognitive aspects such as memory, intellect, or learning and logic ability, in a particular individual relative to other individuals within the same general age population. "Deficiency in attention and/or cognition" also refers to a reduction in any particular individual's functioning in one or more cognitive aspects, for example as occurs in age-related cognitive decline.

Examples of disorders that comprise as a symptom a deficiency in attention and/or cognition that can be treated according to the present invention are dementia, for example Alzheimer's disease, multi-infarct dementia, alcoholic dementia or other drug-related dementia, dementia associated with intracranial tumors or cerebral trauma, dementia

associated with Huntington's disease or Parkinson's disease, or AIDS-related dementia; delirium; amnestic disorder; post-traumatic stress disorder; mental retardation; a learning disorder, for example reading disorder, mathematics disorder, or a disorder of written expression; attention-deficit/hyperactivity disorder; and age-related cognitive decline.

This invention also provides a method of treating a mood disorder or mood episode in a mammal, including a human, comprising administering to said mammal an amount of a selective PDE10 inhibitor effective in treating said disorder or episode.

This invention also provides a method of treating a mood disorder or mood episode in a mammal, including a human, comprising administering to said mammal an amount of a selective PDE10 inhibitor effective in inhibiting PDE10.

Examples of mood disorders and mood episodes that can be treated according to the present invention include, but are not limited to, major depressive episode of the mild, moderate or severe type, a manic or mixed mood episode, a hypomanic mood episode; a depressive episode with atypical features; a depressive episode with melancholic features; a depressive episode with catatonic features; a mood episode with postpartum onset; post-stroke depression; major depressive disorder; dysthymic disorder; minor depressive disorder; premenstrual dysphoric disorder; post-psychotic depressive disorder of schizophrenia; a major depressive disorder superimposed on a psychotic disorder such as delusional disorder or schizophrenia; a bipolar disorder, for example bipolar I disorder, bipolar II disorder, and cyclothymic disorder.

This invention further provides a method of treating a neurodegenerative disorder or condition in a mammal, including a human, which method comprises administering to said mammal an amount of a selective PDE10 inhibitor effective in treating said disorder or condition.

This invention further provides a method of treating a neurodegenerative disorder or condition in a mammal, including a human, which method comprises administering to said mammal an amount of a selective PDE10 inhibitor effective in inhibiting PDE10.

As used herein, and unless otherwise indicated, a "neurodegenerative disorder or condition" refers to a disorder or condition that is caused by the dysfunction and/or death of neurons in the central nervous system. The treatment of these disorders and conditions can be facilitated by administration of an agent which prevents the dysfunction or death of neurons at risk in these disorders or conditions and/or enhances the function of damaged or healthy neurons in such a way as to compensate for the loss of function caused by the dysfunction or death of at-risk neurons. The term "neurotrophic agent" as used herein refers to a substance or agent that has some or all of these properties.

Examples of neurodegenerative disorders and conditions that can be treated according to the present invention include, but are not limited to, Parkinson's disease; Huntington's disease; dementia, for example Alzheimer's disease, multi-infarct dementia, AIDS-related dementia, and Fronto temperal Dementia; neurodegeneration associated with cerebral trauma; neurodegeneration associated with stroke, neurodegeneration associated with cerebral infarct; hypoglycemia-induced neurodegeneration; neurodegeneration associated with epileptic seizure; neurodegeneration associated with neurotoxin poisoning; and multi-system atrophy.

In one embodiment of the present invention, the neurodegenerative disorder or condition comprises neurodegeneration of striatal medium spiny neurons in a mammal, including a human.

In a further embodiment of the present invention, the neurodegenerative disorder or condition is Huntington's disease.

"Neurotoxin poisoning" refers to poisoning caused by a neurotoxin. A neurotoxin is any chemical or substance that can cause neural death and thus neurological damage. An example of a neurotoxin is alcohol, which, when abused by a pregnant female, can result in alcohol poisoning and neurological damage known as Fetal Alcohol Syndrome in a newborn. Other examples of neurotoxins include, but are not limited to, kainic acid, domoic acid, and acromelic acid; certain pesticides, such as DDT; certain insecticides, such as organophosphates; volatile organic solvents such as hexacarbons (e.g. toluene); heavy metals (e.g. lead, mercury, arsenic, and phosphorous); aluminum; certain chemicals used as weapons, such as Agent Orange and Nerve Gas; and neurotoxic antineoplastic agents.

As used herein, the term "selective PDE10 inhibitor" refers to a substance, for example an organic molecule, that effectively inhibits an enzyme from the PDE10 family to a greater extent than enzymes from the PDE 1-9 families or PDE11 family. In one embodiment, a selective PDE10 inhibitor is a substance, for example an organic molecule, having a K_i for inhibition of PDE10 that is less than or about one-tenth the K_i that the substance has for inhibition of any other PDE enzyme. In other words, the substance inhibits PDE10 activity to the same degree at a concentration of about one-tenth or less than the concentration required for any other PDE enzyme.

In general, a substance is considered to effectively inhibition PDE10 activity if it has a K_i of less than or about 10μM, preferably less than or about 0.1μM.

In one embodiment of the therapeutic methods of the invention described herein, the selective PDE10 inhibitor is papaverine.

A "selective PDE10 inhibitor" can be identified, for example, by comparing the ability of a substance to inhibit PDE10 activity to its ability to inhibit PDE enzymes from the other PDE families. For example, a substance may be assayed for its ability to inhibit PDE10 activity, as well as PDE1, PDE2, PDE3A, PDE4A, PDE4B, PDE4C, PDE4D, PDE5, PDE6, PDE7, PDE8, PDE9, and PDE11.

In one embodiment of the therapeutic methods of the invention described above, the selective PDE10 inhibitor is papaverine.

This invention also provides a method of selectively inhibiting PDE10 in a mammal, including a human, comprising administering to said mammal papaverine in an amount effective in inhibiting PDE10.

The term "treating", as in "a method of treating a disorder", refers to reversing, alleviating, or inhibiting the progress of the disorder to which such term applies, or one or more symptoms of the disorder. As used herein, the term also encompasses, depending on the condition of the patient, preventing the disorder, including preventing onset of the disorder or of any symptoms associated therewith, as well as reducing the severity of the disorder or any of its symptoms prior to onset. "Treating" as used herein refers also to preventing a recurrence of a disorder.

For example, "treating schizophrenia, or schizophreniform or schizoaffective disorder" as used herein also encompasses treating one or more symptoms (positive, negative, and other associated features) of said disorders, for example treating, delusions and/or hallucination associated therewith. Other examples of symptoms of schizophrenia and schizophreniform and schizoaffecctive disorders include disorganized speech, affective flattening, alogia, anhedonia, inappropriate affect, dysphoric mood (in the form of, for example, depression, anxiety or anger), and some indications of cognitive dysfunction.

The term "mammal", as used herein, refers to any member of the class "Mammalia", including, but not limited to, humans, dogs, and cats.

This invention also provides for novel assays for screening compounds for identification of compounds that are selective PDE10 inhibitors.

For example, this invention also provides a method for determining whether a chemical compound has activity in selectively inhibiting PDE10, which method comprises: a) applying a chemical compound to a medium spiny neuron culture; and b) measuring whether the phosphorylation of CREB increases in the culture; an increase in the phoshphorylation of CREB thereby determining that the compound applied in step (a) has activity in selectively inhibiting PDE10.

As another example, this invention provides a method for determining whether a chemical compound has activity in selectively inhibiting PDE10, which method comprises: a)

applying a chemical compound to a medium spiny neuron culture; and b) measuring whether the amount of GABA produced by the medium spiny neurons in said culture increases; an increased production of GABA by said medium spiny neurons thereby determining that the compound applied in step (a) has activity in selectively inhibiting PDE10.

A medium spiny neuron culture can be prepared by a person of ordinary skill in the art using known techniques, for example, but not limited to, the techniques described in detail herein, *infra*.

Chemical compounds may be applied to the medium spiny neuron culture for either of the aforementioned assays using known methods. Application of chemical compounds may be automated or manual. Furthermore, a series of chemical compounds may be screened according to either assay by high throughput screening. Optionally, more than one medium spiny neuron culture may be used and/or aliquots of a single medium spiny neuron culture may be used to simultaneously and/or sequentially assay different compounds for activity in selectively inhibiting PDE10. Either of these assays may comprise one or more automated, for example computerized, steps.

CREB phosphorylation in the medium spiny neuron culture(s) may be measured using techniques known to those of ordinary skill in the art. For example, CREB phosphorylation may be measured by homegenizing the treated medium spiny neuron culture Western blotting of the protein mixture resulting therefrom using an antibody specific to CREB. The antibody-CREB complex may be measured according to one or more of many known methods, for example by using a second fluorescent-labeled, readiolabeled antibody, or antibody labeled with an enzyme or enzymye-substrate.

GABA in the medium spiny neuron culture(s) may be measured using techniques known to those of ordinary skill in the art. For example, neurons in the medium spiny neuron culture may first be detected using one of several known nuclear stains and tubulin to identify cells with processes. A fluorescent labeled antibody specific to GABA can than be used to detect GABA-expressing neurons. The number of GABA-expressing neurons may be counted, either by an automated system or visually. Image processing systems other than fluorescence may be used, including, but not limited to, radiolabeled GABA-specific antibody. As another means, the treated medium spiny neuron culture may be homogenized, and GABA therein quantified by any number of known methods, including, but not limited to HPLC, ELISA, or enzymatic reaction.

Brief Description of the Figures

Figure 1: The Figure is a bar graph showing catalepsy in animals versus increasing dose of papaverine. The gray bars represent a papaverine in combination with haloperidol and show the potentiation of haloperidol-induced catalepsy by papaverine. The black bars represent papaverine alone. These black bars show that papaverine did not alone induce catalepsy at a dose of up to 32 mg/kg. More particularly, papaverine was administered at the indicated doses either alone or with haloperidol (0.32 mg/kg) 30 min prior to testing. Each bar is the mean latency for six similarly treated animals to remove both forepaws from an elevated bar. Kruskall-Wallace analysis of variance was used to compare the ranked latencies for papaverine alone versus plus haloperidol. Post hoc analysis indicates that animals dosed with 3.2, 10, and 32 mg/kg papaverine plus haloperidol had significantly (**) longer latencies than that of animals treated with haloperidol alone.

Figure 2: The Figure is two bar graphs each showing the mean + SEM number of crossovers for animals in a shuttle box study for the first 60 minutes following substance administration. The top graph compares papaverine's effects on movement alone to papaverine's effects on amphetamine-induced movement. The bottom graph compares papaverine's effects on movement alone to papaverine's effects on PCP-induced movement. Amphetamine was administered at 1 mg/kg, i.p. PCP was administered at 3.2 mg/kg, i.p. Papaverine was co-administered with either agent at a dose of 32 mg/kg, i.p. Data represents the mean + SEM crossovers for the first 60 min following drug administration for n-=8 rats/group.

** $p<0.01$ versus vehicle/vehicle control; * $p<0.05$ versus vehicle/PCP by Students t-test

Figure 3. The concentration of cAMP in forskolin-stimulated medium spiny neuron culture is shown. The effect of a selective PDE 10 inhibitor, a selective PDE 1B inhibitor, and a selective PDE 4 inhibitor on cAMP concentration in the stimulated neurons is also shown.

Figure 4. The concentration of cGMP in SNAP-stimulated medium spiny neuron culture is shown. The effect of a selective PDE 10 inhibitor, a selective PDE 1B inhibitor, and a selective PDE 4 inhibitor on cGMP concentration in the stimulated neurons is also shown.

Figure 5. A comparison of the relative effect of a selective PDE 10 inhibitor and of rolipram (a selective PDE 4 inhibitor) on the phosphorylation of CREB (Cyclic AMP Response Element Binding Protein) in medium spiny neuron culture. The amount of phosphorylated CREB was measured by Western blot.

Figure 6. The relative numbers of GABA-positive medium spiny neurons is shown for neurons treated with a selective PDE 10 inhibitor, a selective PDE 4 inhibitor (rolipram), and a selective PDE 1B inhibitor.

Detailed Description of the Invention

In the present invention, we identify a selective PDE10 inhibitor. We use this and similarly selective PDE10 inhibitors to determine that PDE10 inhibitors have a characteristic and unique effect on cyclic nucleotide metabolism in a population of neurons which express PDE10 at a high level, the striatal medium spiny neurons. These inhibitors also increase the phosphorylation of the transcription regulator cAMP response element binding protein (CREB) in these neurons. CREB phosphorylation is associated with changes in the transcription of a variety of genes. This, in turn, has functional consequences which include, but are not limited to, effects on neuronal survival and differentiation and changes in synaptic organization as reflected in augmentation of long term potentiation. We disclose here that PDE10 inhibitors have such an effect in the medium spiny neurons, namely, to promote the differentiation of these neurons to a GABA phenotype. Furthermore, we disclose that PDE10 inhibitors have functional effects on the central nervous system in intact mammals. Specifically, we disclose that PDE10 inhibitors given to rats potentiate catalepsy induced by the dopamine D2 receptor antagonist haloperidol, but do not cause catalepsy when given alone at the same doses. PDE10 inhibitors also inhibit the hyperlocomotion induced by the NMDA receptor antagonist phencyclidine. These findings support the claims that PDE10 inhibitors affect the central nervous system and can be therapeutically useful to treat the disorders of the central nervous system recited in the claims.

PDEs 2, 3 and 5, isozymes, including human PDEs, can, for example, be prepared from corpus cavernosum; PDE1, isozymes including human, from cardiac ventricle; and PDE4, isozymes, including human, from skeletal muscle. PDE6 can be prepared, for example, from canine retina. Description of enzyme preparation from native tissue is described, for example, by Boolell, M. et al., Int. J. Impotence Research 8:7-52, 1996, incorporated herein by reference.

PDEs 7-11 can similarly be prepared from native tissue. Isozymes from the PDEs 7-9 and 11 families can alternatively be generated from full length human recombinant clones transfected into, for example, SF9 cells as described in Fisher, D.A., et al., Biochem. Biophys. Res. Comm. 246, 570-577, 1998; Soderling, S.H. et al., PNAS 96: 7071-7076, 1999; Fisher, D.A. et al., J. Biol. Chem. 273, 15559-15564, 1998b; and Fawcett, L., et al., PNAS 97: 3702-3707, 2000; respectively. PDE10 can also be generated from a rat recombinant clone transfected into SF9 cells (Fujishige et al., European Journal of Biochemistry, Vol. 266, 1118-1127 (1999)). The enzymes are then prepared by FPLC from the soluble fraction of cell lysates as described for PDE6. The aforementioned references are incorporated in their entireties herein by reference.

In one assay, a substance is screened for inhibition of cyclic nucleotide hydrolysis by the PDE10 and the PDEs from the other gene families. The cyclic nucleotide substrate concentration used in the assay of each individual PDE is 1/3 of the K_m concentration, allowing for comparisons of IC_{50} values across the different enzymes. PDE activity is measured using a Scintillation Proximity Assay (SPA)-based method as previously described (Fawcett et al., 2000). The effect of PDE inhibitors is determined by assaying a fixed amount of enzyme (PDEs 1-11) in the presence of varying substance concentrations and low substrate, such that the IC_{50} approximates the K_i (cGMP or cAMP in a 3:1 ratio unlabelled to [^{3}H]-labeled at a concentration of 1/3 Km). The final assay volume is made up to 100µl with assay buffer [20 mM Tris-HCl pH 7.4, 5 mM $MgCl_2$, 1 mg/ml bovine serum albumin]. Reactions are initiated with enzyme, incubated for 30-60 min at 30°C to give <30% substrate turnover and terminated with 50 µl yttrium silicate SPA beads (Amersham) (containing 3 mM of the respective unlabelled cyclic nucleotide for PDEs 9 and 11). Plates are re-sealed and shaken for 20 min, after which the beads were allowed to settle for 30 min in the dark and then counted on a TopCount plate reader (Packard, Meriden, CT). Radioactivity units can be converted to percent activity of an uninhibited control (100%), plotted against inhibitor concentration and inhibitor IC_{50} values can be obtained using the 'Fit Curve' Microsoft Excel extension.

One example of a selective PDE10 inhibitor is papaverine (1-[(3,4-dimethoxyphenyl)methyl]-6,7-dimethoxyisoquinoline). Papaverine is a known effective smooth muscle relaxant used in the treatment of cerebral and coronary vasospasm as well as for erectile dysfunction. Although the basis of these therapeutic activities is not well understood, they are generally ascribed to papaverine's activity as a nonselective phosphodiesterase inhibitor (The Pharmacological Basis of Therapeutics; Sixth Edition; A.G. Gilman, L.S. Goodman, A. Gilman (eds.) Macmillan Publishing Co., New York, 1980, p. 830). Although papaverine is a naturally occurring plant alkaloid, its complete biosynthesis has been described, for example in Brochmann-Hanssen et al., J. Pharm. Sci. 60:1672, 1971, which is incorporated herein by reference.

A selective PDE10 inhibitor may be administered according to the present invention either alone or in combination with pharmaceutically acceptable carriers, in either single or multiple doses. Suitable pharmaceutical carriers include inert solid diluents or fillers, sterile aqueous solutions and various organic solvents. The pharmaceutical compositions formed thereby can then be readily administered in a variety of dosage forms such as tablets, powders, lozenges, syrups, injectable solutions and the like. These pharmaceutical compositions can, if desired, contain additional ingredients such as flavorings, binders, excipients and the like.

Thus, for purposes of oral administration, tablets containing various excipients such as sodium citrate, calcium carbonate and calcium phosphate may be employed along with various disintegrants such as starch, methylcellulose, alginic acid and certain complex silicates, together with binding agents such as polyvinylpyrrolidone, sucrose, gelatin and acacia. Additionally, lubricating agents such as magnesium stearate, sodium lauryl sulfate and talc are often useful for tabletting purposes. Solid compositions of a similar type may also be employed as fillers in soft and hard filled gelatin capsules. Preferred materials for this include lactose or milk sugar and high molecular weight polyethylene glycols. When aqueous suspensions or elixirs are desired for oral administration, the essential active ingredient therein may be combined with various sweetening or flavoring agents, coloring matter or dyes and, if desired, emulsifying or suspending agents, together with diluents such as water, ethanol, propylene glycol, glycerin and combinations thereof.

For parenteral administration, solutions containing a selective PDE10 inhibitor in sesame or peanut oil, aqueous propylene glycol, or in sterile aqueous solution may be employed. Such aqueous solutions should be suitably buffered if necessary and the liquid diluent first rendered isotonic with sufficient saline or glucose. These particular aqueous solutions are especially suitable for intravenous, intramuscular, subcutaneous and intraperitoneal administration. The sterile aqueous media employed are all readily available by standard techniques known to those skilled in the art.

A selective PDE10 inhibitor can be administered in the therapeutic methods of the invention orally, transdermally (e.g., through the use of a patch), parenterally (e.g. intravenously), rectally, or topically. In general, the daily dosage of PDE10 inhibitor for treating a disorder or condition according to the methods described herein will generally range from about 0.01 to about 100 mg/kg body weight of the patient to be treated. As an example, a selective PDE10 inhibitor can be administered for treatment of, for example, a psychotic disorder or Huntington's disease, to an adult human of average weight (about 70kg) in a dose ranging from about 1 mg up to about 7000 mg per day, preferably from about 1 mg to about 1000 mg per day, in single or divided (i.e., multiple) portions. Variations based on the aforementioned dosage ranges may be made by a physician of ordinary skill taking into account known considerations such as the weight, age, and condition of the person being treated, the severity of the affliction, and the particular route of administration chosen.

The following Examples illustrate the present invention. It is to be understood, however, that the invention, as fully described herein and as recited in the claims, is not intended to be limited by the details of the following Examples.

EXAMPLES

Example 1. Selective PDE10 Inhibitors: Papaverine:

Papaverine was screened for inhibition of cyclic nucleotide hydrolysis by PDE10 and a battery of PDEs from the other gene families. The cyclic nucleotides substrate concentration used in the assay of each individual PDE was 1/3 of the Km concentration. This allows for comparisons of IC_{50} values across the different enzymes.

PDE activity was measured using the assay with yttrium silicate SPA beads described above in the Detailed Description section. Radioactivity units were converted to percent activity of an uninhibited control (100%), plotted against inhibitor concentration and inhibitor IC_{50} values obtained using the 'Fit Curve' Microsoft Excel extension.

We observed that papaverine was an exceptionally potent, competitive inhibitor of PDE10 with an IC_{50} value of 18 nM (Table 1). Papaverine was considerably less potent against all other PDEs tested. After PDE10, the enzyme inhibited most potently by papaverine was PDE4D with an IC_{50} of 320 nM, a value 19-fold lower than that for PDE10. Thus, these data reveal for the first time that papaverine is a selective PDE10 inhibitor and that this compound can be used in studies of this enzyme's physiology.

Table 1. IC_{50} values for papaverine inhibition of the listed PDEs. IC_{50}s were determined for each enzyme at a substrate concentration of 1/3 the Km value to allow for comparisons across enzymes. The PDE10 selectivity ratio is the IC_{50} value for a given PDE divided by the IC_{50} value for PDE10.

Isozyme	IC_{50}, µM	Selectivity Ratio (IC_{50}/IC_{50}, PDE10)
PDE10	0.018	-
PDE1	37	2,055
PDE2	9	500
PDE3A	1.3	72
PDE4A	1.9	105
PDE4B	1.4	78
PDE4C	0.8	44
PDE4D	0.32	18
PDE5	8	444
PDE6	0.86	48
PDE7	27	1,500
PDE8	> 10	> 555
PDE9	400	20,000
PDE11	11	611

<u>Example 2. Effects of a Selective PDE10 Inhibitor on Cyclic Nucleotide Metabolism in Medium Spiny Neurons:</u>

We examined the effects of papaverine, a selective PDE10 inhibitor as determined in Example 1, on cyclic nucleotide metabolism in rat medium spiny neurons in primary culture.

Neurons cultured from E17 rat embryo striatum in the presence of BDNF displayed a phenotype very similar to that described previously (Ventimiglia et al., Eur. J. Neurosci. 7 (1995) 213-222). Approximately 50 % of these neurons stain positive for GABA immunoreactivity confirming the presence of medium spiny neurons in the cultures. Expression of PDE-10 message in these cultures at 4-6 DIV was confirmed by RNAase protection assay.

The striatal cultures were prepared as previously described (Ventimiglia et al., Eur. J. Neurosci. 7: 213-222, 1995). Briefly, striata (caudate nucleus and putamen) are dissected from E17 rats, were dissociated to produce a single cell suspension and plated at a density of 5×10^4 neurons/well in multiwell plates coated with poly-L-ornithine/laminin. The cells were

plated in Neurobasal medium with B27 supplements and BDNF (100ng/mL). Experiments were typically performed after 4 days *in vitro*. Medium spiny neurons comprise the majority of cells in these cultures (50 to 60%, as confirmed by GABA immunoreactivity).

For the RNAse protection assay, RNA was prepared from these primary cultures of rat medium spiny neurons by centrifugation at 150, 000 x g at 20°C for 21 hr through a 5.7 M cesium chloride gradient as previously described (Iredale, PA, et al., Mol. Pharmacol.50: 1103-1110, 1996). The RNA pellet was resuspended in 0.3 M sodium acetate, pH 5.2, precipitated in ethanol and the concentration determined by spectrophotometry. The PDE10 riboprobe was prepared by PCR amplification of a 914 bp fragment isolated from mouse cDNA (corresponding to bp 380- bp 1294). This fragment was then cloned into pGEM3Zf. The vector was linearized and T7 RNA polymerase was used to synthesize [^{32}P]-labeled antisense riboprobe. The RNase protection assay was performed using the RPAII kit (Ambion). Briefly, 5 μg of total cellular RNA was hybridized with [^{32}P]-labeled PDE10 riboprobe (~105 cpm/sample) overnight at 42°C. The following day the samples were incubated with RNase A and T1 for 30 min at 37°C and the protected double-stranded RNA fragments were then precipitated and run on a 6% polyacrylamide gel containing urea.

For analyzing effects of papaverine on cyclic nucleotides, the striatal cell cultures, after four days *in vitro,* were washed with Ca^{2+}/Mg^{+} free phosphate buffered saline and preincubated for an hour in a buffer containing Ca^{2+}/Mg^{+} free phosphate buffered saline, 30mM HEPES, $CaCl_2$1mM, dextrose 1mg/mL, and $MgCl_2$ 5mM. The striatal cells were exposed to phosphodiesterase inhibitors and incubated for twenty minutes at 37 degrees Celsius. When measuring cGMP, the neurons were stimulated with sodium nitroprusside, a nitric oxide source for two minutes following the 20-minute incubation with compound. When measuring cAMP, the neurons were stimulated with forskolin, an activator of adenylate cyclase for the duration of the twenty minute compound incubation. The cells were lysed using a 9:1 combination of cAMP SPA direct screening Assay Buffer (0.05M acetate with 0.01% sodium azide) and Buffer A (133mg/mL dodecyltrimethylammonium bromide) and the lysates were frozen on dry ice. A cGMP [I125] or cAMP [I125] scintillation proximity assay (SPA) system (Amersham code RPA 540 and RPA 559, respectively) was used to detect the concentration of the respective cyclic nucleotide in the cell lysate.

Papaverine alone did not produce measurable changes in the basal level of either cAMP or cGMP in the striatal cultures. We therefore examined the effects of the compound under conditions in which cAMP or cGMP synthesis was stimulated with forskolin or the NO donor sodium nitroprusside (SNP), respectively. Stimulation of the cultures with forskolin (0.1-10 μM) for 20 min resulted in a concentration-dependent increase in cAMP levels.

Similarly, brief exposure of the cultures to SNP (3-1000 μM) for 2 min resulted in a concentration-dependent increase in cGMP levels. Forskolin alone (10 μM) did not alter cGMP concentrations nor did SNP (300 μM) increase cAMP levels. In order to determine the effects of papaverine on cAMP and cGMP metabolism, striatal cultures were incubated with various concentrations of the compound and then stimulated with submaximally effective concentrations of either forskolin (1 μM) or SNP (100 μM). These concentrations of forskolin or SNP caused a 2-3 fold increase over basal in cAMP and cGMP, respectively. Papaverine caused a concentration-dependent increase in SNP-induced cGMP accumulation with an EC_{200} (concentration of the inhibitor yielding a 2-fold increase) value of 11.7 μM (Table 2). A maximal effect was observed at 100 μM, at which cGMP levels were elevated 5-fold over that in cultures stimulated with SNP alone. Papaverine also caused an increase in cAMP accumulation in forskolin-stimulated cultures. However, the compound was 3.3-fold less potent at promoting an increase in cAMP than for cGMP. The effects of papaverine in the striatal cultures were compared to other PDE inhibitors with different selectivities (Table 2). IBMX, a nonselective inhibitor caused a concentration dependent (3-100 μM) increase in both cGMP and cAMP accumulation in SNP- or forskolin-stimulated cultures with EC_{200} values of 19 and 30 μM, respectively. The selective PDE4 inhibitor rolipram increased forskolin stimulated cAMP accumulation with an EC_{200} value of 2.5 μM and required 10-fold higher concentrations to double the rate of cGMP accumulation. Zaprinast, an inhibitor of cGMP preferring PDEs, doubled the cAMP levels in these neurons at a concentration of 98 μM. However, 100 μM of this compound did not quite double the level of cGMP. These data reveal for the first time that papaverine has a unique effect on cyclic nucleotide regulation in medium spiny neurons and that this effect is due to the selectivity for PDE10.

Table 2.

EC_{200} values for the elevation of cGMP or cAMP in primary cultures of rat striatal neurons. The EC_{200} values refer to the concentration producing a 200% increase in cGMP or cAMP in SNP- or forskolin-stimulated cultures, respectively. Each value is the mean +/- S.E.M. from the indicated number of experiments (n). In each experiment, each condition was replicated in 3-6 sister cultures.

Compound	cGMP	cAMP	cAMP/cGMP
	EC_{200} in μM, ± S.E.M. (n)		
Papaverine	11.7 ± 8.2 (4)	38.3 ± 11.4 (4)	3.3
Rolipram	29.2 ± 10.3 (3)	2.5 ± 2.0 (3)	0.09
Zaprinast	98.3 ± 10.3 (3)	>100 (3)	1
IBMX	19.5 (1)	30.2 (2)	1.5

Example 3. Effect of a Selective PDE 10 Inhibitor in Animal Model of Basal Ganglia Function:

Studies in human and non-human mammals indicate that the basal ganglia regulate a range of motor as well as cognition and emotional/appetitive behaviors (Graybiel, A.M. Current Biology 10 (14):R509-11, 2000). Experimental models in rodents have been developed which can be used to assess the effects of compounds on basal ganglia function. We find that papaverine has an unanticipated unique profile of behavioral effects in two such models.

The effect of papaverine alone and in combination with haloperidol was tested for the ability to induce catalepsy in male CD rats. This animal model is used to analyze the effects of compounds on basal ganglia output. Papaverine (1.0, 3.2, 10, or 32 mg/kg.) or vehicle was administered subcutaneously. For some experiments, this was immediately followed by haloperidol. Thirty minutes after drug administration(s), the degree of catalepsy was quantified by placing the animals forepaws on an elevated (10 cm) bar (1 cm diameter) and determining the latency to remove both forepaws from the bar, with a latency cutoff of 30 sec. Latencies were ranked within each treatment group for comparison by a Kruskall-Wallace analysis of variance. Post hoc analysis was by the Mann Whitney U test.

The antipsychotic agent haloperidol produces robust catalepsy in this model, as previously described (Chartoff, E et al., J Pharmacol. Exp. Ther. 291:531-537, 1999). A maximally effective dose of haloperidol was found to be 1 mg/kg, s.c. In contrast, papaverine did not induce catalepsy when administered alone at a dose of up to 32 mg/kg s.c. (p = 0.86). However as shown in Figure 1, papaverine potentiated the cataleptic effect of a submaximal

dose of haloperidol (0.32 mg/kg, s.c. in 0.3% tartaric acid) ($p<0.001$). The minimum effective dose of papaverine for potentiation of haloperidol-induced catalepsy is 3.2 mg/kg, s.c. This experiment demonstrated that papaverine can alter basal ganglia output in a direction consistent with antipsychotic activity.

Example 4. Effect of A Selective PDE 10 Inhibitor in Animal Model for Psychosis:

We next examined the effect of papaverine on locomotor activity in rats as measured in a shuttle box. Reduction of PCP-stimulated locomotion in rodents is accepted as a primary screen in the search for novel antipsychotic agents. Newer atypical antipsychotic agents generally demonstrate a preferential inhibition of PCP- versus amphetamine-stimulated locomotor activity. Adult, male, Sprague-Dawley rats (250-300 g) were obtained from Charles River (Wilmington, MA). Locomotor activity was assessed using crossover behavior in commercially available shuttle boxes (Coulbourn Instruments, Allentown, PA). Data was collected in 5 minute intervals for 1 hour after drug administration. Animals received either vehicle (5% DMSO, 5% Emulphor, 90% Saline) phencyclidine (PCP, Sigma Chem. Co..) or amphetamine Sulfate (RBI) followed immediately by either vehicle or test compound. Statistical analysis was performed using the Student's t-test.

The psychostimulants amphetamine and phencyclidine (PCP) both produce a robust increase in locomotor activity in this model. Papaverine alone (32 mg/kg, i.p.) produced a small decrease in locomotor activity which was statistically significant in some studies (Figure 2). However, this same dose of papaverine produced a significant reduction in the locomotor activity stimulated by 3.2 mg/kg, i.p. phencyclidine without effecting that produced by a behaviorally equivalent dose of amphetamine (1 mg/kg, i.p.).

In another experiment using such a locomotor animal screen, papaverine was coadministered with amphetamine (1 mg/kg, s.c.) or PCP (3.2 mg/kg, s.c.) and locomotion measured for 30 minutes. In this experiment, papaverine effectively inhibited both amphetamine and PCP stimulated locomotion.

The results of both of the above experiments show that papaverine has a behavioral effect on locomotion consistent with an antipsychotic profile.

In Examples 5-7, below, the selective PDE10 inhibitor and the selective PDE1B inhibitor were determined according to an assay as described in the Detailed Description of the Invention (Table 3 shows the IC_{50} in μM of the selective PDE10 inhibitor for PDEs 1, 2, 3, 4, 5, 7, 8, 9, 10, and 11):

Table 3.

IC_{50} values for a compound demonstrated to be a selective PDE10 inhibitor. IC_{50}s were determined for each enzyme at a substrate concentration of approximately 1/3 the Km value.

Isozyme	IC_{50}, µM
PDE10	0.04
PDE1A	0.97
PDE2	0.86
PDE3A	1.2
PDE4D	1.6
PDE5	3.2
PDE7B	6.4
PDE8A	> 10
PDE9	4.8
PDE11	0.78

<u>Example 5. Effects of PDE Inhibitors on cAMP and cGMP Accumulation in Medium Spiny Neurons:</u>

Medium spiny neuron cultures were prepared as discussed in Example 2 from striata from E17 or E18 rat embryos. The striata were digested with trypsin and the dissociated cells plated on poly-L-omithine/laminin coated plates in Neurobasal medium containing B27 supplement. For assays of cyclic nucleotide formation and CREB phosphorylation, neurons are also supplemented with 50 ng/ml BDNF and used at 6 DIV. At this time, approximately 90% of the cells are of neuronal morphology and 50% stain positively for GABA.

In medium spiny neuron culture, we found that selective inhibitors for PDE10 and PDE1B, and rolipram (which is selective for PDE4) potentiate the increase in accumulation of cAMP (Fig. 3) or cGMP (Fig. 4) stimulated with forskolin or SNAP, respectively. However, there was no detectable change in cAMP or cGMP levels when the compounds were added in the absence of a stimulus.

The PDE inhibitors were differentiated by the potencies with which they potentiated the increase in cAMP versus cGMP (Table 4). In Table 4, potency is expressed as the EC_{200}, i.e. the concentration of PDE inhibitor which increases by 200% the forskolin- or SNAP-induced increase in cAMP or cGMP, respectively.

Table 4
Medium Spiny Neurons, EC_{200}, µM

	cGMP	cAMP	cAMP/cGMP
Selective PDE10 inhibitor	4.0 ± 1.0	28.9 ± 7.0	7.2
Selective PDE1B inhibitor	1.4 ± 0.4	3.9 ± 1.3	2.8
Rolipram	71.1 ± 9.9	2.0 ± 0.2	0.03

Example 6. Effect of PDE Inhibitors on CREB Phosphorylation in Medium Spiny Neurons:

cAMP and cGMP activate protein kinases PKA and PKG, respectively. Both kinases are capable of phosphorylating the transcription regulator CREB. We examined the effects of the selective PDE inhibitors in Table 3 on phosphorylation of CREB as a downstream event in the cyclic nucleotide signaling cascade.

Stimulation with forskolin produced a robust increase in CREB phosphorylation, as measured by Western blotting. The selective PDE 10 inhibitor and rolipram also increased CREB phosphorylation as measured by Western blotting. A comparison of the effect of the selective PDE 10 inhibitor and of rolipram is shown in Fig. 5. The rank order of efficacy in increasing CREB phosphorylation was determined to be forskolin > selective PDE 10 inhibitor > rolipram. The selective PDE 1B inhibitor was inactive in increasing CREB phosphorylation.

Example 7. Effect of PDE Inhibitors on Differentiation of Medium Spiny Neurons:

The transcriptional events activated following CREB phosphorylation are involved in the survival and differentiation of neurons. We investigated whether the PDE inhibitors in Table 3 effect the survival and differentiation of the medium spiny neurons. These experiments were conducted using a protocol used by Ventimiglia et al. (see Ventimiglia et al., 1995, *supra*) to assay the effects of BDNF on these processes in medium spiny neurons. Specifically, the PDE inhibitors were added to the medium spiny neuron culture medium at the time of plating, and then at 6 DIV various parameters related to neuronal survival and differentiation were quantified using the Array Scan System from Cellomics, Inc (Pittsburgh, PA, USA).

Of the parameters examined, we found that the selective PDE 10 inhibitor strikingly increased the number of GABAergic neurons. Cells could be stained as follows: blue-nuclei;

green-neuron; red-neuron staining positively for GABA. The selective PDE 10 inhibitor was as effective as BDNF, whereas rolipram and the selective PDE 1B inhibitor had no effect (Fig. 6).

Discussion

A high expression of PDE10 mRNA in striatum, nucleus accumbens, and olfactory tubercle using *in situ* hybridization has already been reported (Seeger, T. F. Et al., *supra*). Using monoclonal antibody for PDE10 protein, a correspondingly high level of PDE10 protein in these brain regions has also been found (Menniti, F.S., Strick, C.A., Seeger, T.F., and Ryan, A.M., *Immunihistochemical localization of PDE10 in the rat brain*, *supra*). Within the striatum and n. accumbens, we found PDE10 mRNA expressed at high levels in the medium spiny neurons. Medium spiny neurons are the output neurons of the striatum, n. accumbens, and olfactory tubercle; and represent approximately 95 % of all the neurons in these brain structures. Furthermore, a high level of PDE10 protein was observed in the projections (axons and terminals) of medium spiny neurons projecting from the striatum, n. accumbens, and olfactory tubercle into other brain regions, including the globus pallidus and substantia nigra. These latter brain regions themselves have low or undetectable levels of PDE10 mRNA. Therefore, the high level of PDE10 protein in these regions arises from the axons and terminals of the medium spiny neurons. In addition, PDE10 mRNA and protein is expressed at lower levels in neurons of other brain regions, including the cortex, hippocampus and cerebellum.

The high levels of PDE10 expression in the striatum and nucleus accumbens are particularly interesting given that these are the major cortical input nuclei of the basal ganglia as well as the principal terminal fields for the midbrain dopaminergic projections. The striatum and its ventral extension, the nucleus accumbens, receive glutamatergic afferents from virtually every region of the cerebral cortex and function as a subcortical integration site for a wide range of cortical activities. The dorsal striatum is generally considered to be involved in the regulation of motor behavior whereas the ventral regions, including the accumbens, function in the regulation of emotional/appetitive behaviors. Thus, we believe that PDE10 is likely to be involved in signaling pathways that regulate a number of these basic physiological processes.

In fact, we disclose that inhibition of PDE10 has effects on cyclic nucleotide metabolism and CREB signaling in the medium spiny neurons that are distinct from those caused by inhibition of PDE 4 or PDE 1, the other major PDEs expressed by these neurons. We also disclose that PDE10 inhibitors have demonstrable effects on basal ganglia function *in vivo*.

Selective PDE10, 4 and 1 inhibitors each increased the accumulation of cGMP and/or cAMP in medium spiny neurons stimulated with SNAP or forskolin, respectively (Figs. 3 and 4). However, the inhibitors differed in the ratio of potency for affecting the two cyclic nucleotides (Table 3). These differences likely reflect the intrinsic affinity of PDEs 10, 4, and 1B for the two cyclic nucleotides as well as differential access of the different PDEs to cyclic nucleotide pools. Notably, these inhibitors have no measurable effect on cAMP and cGMP levels in the absence of stimulation. Phosphorylation of CREB is one of the downstream events activated by the cyclic nucleotide signaling cascades. We demonstrate that a selective PDE10 inhibitor and a selective PDE 4 inhibitor increased CREB phosphorylation, with the selective PDE 10 inhibitor being more potent and efficacious. These effects occur when the compounds are added without other stimuli and, therefore, in the absence of detectable changes in cyclic nucleotide levels. We have shown that a selective PDE 1B inhibitor is inactive. These results indicate that PDE10 plays a unique role in cyclic nucleotide signaling in medium spiny neurons and, in particular, PDE10 appears to be associated with the regulation of CREB phosphorylation.

The distinct effects of PDE10 inhibition elucidated in the *in vitro* systems correspond to unique effects of PDE10 inhibition on the function of the basal ganglia *in vivo*. We disclose that the selective PDE10 inhibitor papaverine potentiates the cataleptic effect of the dopamine D2 receptor antagonist haloperidol, without producing catalepsy alone. Furthermore, this compound reduces the locomotor hyperactivity induced by the NMDA receptor antagonist phencyclidine. This pharmacological profile of papaverine predicts that it and all PDE10 inhibitors would be useful for the treatment of neurological and psychiatric disorders which involve dysfunction within the basal ganglia, as discussed below.

Cortical input to the striatum provides the primary excitatory drive for the GABAergic medium spiny neurons. Glutamatergic activation of the medium spiny neurons is in turn regulated by the massive dopaminergic input from the midbrain. The antagonistic nature of these two afferent systems has been demonstrated in numerous studies. For example, locomotor stimulant activity in laboratory animals can be produced by either dopamine receptor agonists or antagonists of the NMDA subtype of the glutamate receptor (Carlsson, M.L. and Carlsson, A. Trends Neurosci.13:272-276, 1990). The cataleptic effect of D_2 dopamine receptor antagonists such as haloperidol is reduced by NMDA receptor antagonists as is haloperidol-induced gene expression (Chartoff, E et al., J Pharmacol. Exp. Ther. 291:531-537, 1999). More recently, it has been demonstrated that the blockade of D_2 dopamine receptors results in an increase in the phosphorylated or activated state of striatal NMDA receptors (Leveque et al., Journal of Neuroscience 20(11):4011- 4020, 2000).

The recognition that all clinically effective antipsychotics possess potent D_2 antagonist activity lead to the original hypothesis that the symptoms of schizophrenia are the result of excessive activity in the mesolimbic dopamine system. The ability of a chemical compound to reduce the stimulant properties of direct or indirect dopamine agonists became an important laboratory test in the search for new antipsychotic agents. More recently, the ability of NMDA receptor antagonists such as PCP to faithfully reproduce the positive, negative and cognitive symptoms of schizophrenia in man (Luby et al., 1959; Rosenbaum et al, 1959; Krystal et al. 1994) has lead to the development of the hypofrontality theory of schizophrenia. Simply put, this hypothesis proposes that striatally-mediated behavioral inhibition is deficient in schizophrenia as a consequence of reduced glutamatergic and specifically, NMDA receptor-mediated, neurotransmission. This hypothesis is entirely consistent with the known antipsychotic effect of D_2 dopamine receptor antagonists given their ability to disinhibit directly or indirectly cortical input to the striatum (as described above). The fidelity with which PCP replicates the symptoms of schizophrenia in humans has lead to the use of PCP-stimulated locomotion in rodents as a primary screen in the search for novel antipsychotic agents. The demonstration that newer and presumably more efficacious atypical antipsychotic agents demonstrate preferential activity against PCP- over amphetamine-stimulated locomotor activity would appear to supports this approach (Gleason S.D. and Shannon H.E. Psychopharmacol. 129:79-84, 1997).

Although current approaches to antipsychotic therapy generally target membrane receptors, we propose here that intracellular manipulations of PDE10 within the medium spiny neurons can also produce antipsychotic effects. Increases in cAMP and PKA activity are known to enhance the response of striatal neurons to glutamate agonists including NMDA (Colwell, C.S. and M.S. Levine, J Neuroscience 15(3)1704-1713, 1995). The neuroleptic action of haloperidol is also dependent on increases in cAMP levels (Ward, R.P. and D.M. Dorsa, Neuroscience 89(3):927-938, 1999) and PKA activation (Adams, M.R. et al., Proc Natl Acad Sci USA 94:12157-12161, 1997). Striatal cGMP levels are also increased after D_2 receptor blockade (Altar, C. A. et al., Eur J. Pharmacol. 181:17-21, 1990), and PKG is known to phosphorylate some of the same downstream substrates as PKA, including the endogenous inhibitor of protein phosphatase I, DARP (Greengard P et al., Brain Res. Rev. 26:274-284, 1998). Therefore, we hypothesized that agents able to selectively increase cyclic nucleotide levels in medium spiny neurons in the striatum could reasonably be expected to augment striatal function with a resulting antipsychotic effect, and that a PDE10 inhibitor will have therapeutic efficacy in the treatment of psychosis because such a compound will inhibit the PDE10 catalyzed metabolism of cAMP and cGMP, increasing the levels of these cyclic nucleotides in the medium spiny neurons.

In addition to psychosis, abnormal function of the basal ganglia has been implicated in a variety of neuropsychiatric conditions including attention-deficit/hyperactivity disorder (ADHD) and related attentional disorders (Seeman, P. et al., Molecular Psychiatry 3:386-96, 1998), depression (Kapur, S., Biol. Psychiatry 32:1-17, 1992; Willner, P., Brain Res. 287:225-236, 1983) obsessive comulsive disorders including Tourette's syndrome and other tic disorders (Graybiel AM. Rauch SL. Toward a neurobiology of obsessive-compulsive disorder. Neuron. 28(2):343-7, 2000) and substance abuse (Self, D.W. Annals of Med. 30:379-389, 1998). Several neurological disorders including Parkinson's disease, restless leg syndrome (Hening, W. et al., Sleep 22:970-999, 1999) and Huntington's disease (Vonsattel JP et al., Neuropathological classification of Huntington's disease. J. Neuropathol. Exp. Neurol. 44:559-577. 1985) are also linked to basal ganglia dysfunction. Thus, based on our studies described herein, we believe that a PDE10 inhibitor will have a therapeutic impact on such disorders.

CREB phosphorylation induces transcription of a variety of genes which can have a variety of effectos on neuronal function, including enhancing the survival and/or differentiation of neurons. We disclose that selective PDE10 inhibitors can increase the differentiation of medium spiny neurons to a GABAergic phenotype (Fig. 6). Rolipram (the selective PDE4 inhibitor) and the selective PDE 1B inhibitor did not demonstrate such activity (Fig. 7).

The effects of PDE10 inhibition on CREB phosphorylation are particularly noteworthy with regard to the treatment of neurodegenerative conditions such as Huntington's disease.

Also, CREB phosphorylation in medium spiny neurons and differentiation of medium spiny neurons to a GABAergic phenotype each provide a useful means for identifiecation of organic compounds having activity as selective PDE 10 inhibitors.

The data herein indicate a unique role for PDE10 in the differentiation and/or survival of medium spiny neurons. These neurons are selectively vulnerable in Huntington's disease and it has been hypothesized that this may result from a loss of trophic support for these neurons (Zuccato et al. Loss of Huntingtin-mediated BDNF gene transcription in Huntington's disease. Science. 293:493-498, 2001). We conclude that selective PDE 10 inhibitors have neurotrophic activity with respect to medium spiny neurons. We furthermore conclude that PDE 10 inhibitors are likely to have neurotrophic activity with respect to any neurons that express PDE 10, and that PDE 10 inhibitors are therefore useful for the treatment of neurodegenerative diseases, including, but not limited to, the neuodegenerative diseases identified herein.

Finally, PDE10 mRNA and protein are expressed also in neurons of the hippocampus and cortex. Since cognitive processes are dependant on hippocampus and cortex functioning, we believe that PDE10 also plays a role in cognitive processes and that a PDE10

inhibitor can also be used to treat disorders having a characteristic component of deficient cognitive and/or attention function, such as Alzheimer's disease and age-related cognitive decline (ARCD).

Claims

1. A method for determining whether a chemical compound has activity in selectively inhibiting PDE10, which method comprises:

a) applying a chemical compound to a medium spiny neuron culture; and

b) measuring whether the phosphorylation of CREB increases in the culture;

an increase in the phoshphorylation of CREB thereby determining that the compound applied in step (a) has activity in selectively inhibiting PDE10.

2. A method for determining whether a chemical compound has activity in selectively inhibiting PDE10, which method comprises:

a) applying a chemical compound to a medium spiny neuron culture; and

b) measuring whether the amount of GABA produced by the medium spiny neurons in said culture increases;

an increased production of GABA by said medium spiny neurons thereby determining that the compound applied in step (a) has activity in selectively inhibiting PDE10.

3. A method of treating a disorder selected from obsessive/compulsive disorders, Tourette's syndrome, and other tic disorders in a mammal, which method comprises administering to said mammal an amount of a selective PDE10 inhibitor effective in treating said disorder.

4. A method of treating a neurodegenerative disorder or condition in a mammal, which method comprises administering to said mammal an amount of a selective PDE10 inhibitor effective in treating said disorder or condition.

5. A method according to claim 4, wherein the neurodegenerative disorder or condition is selected from Parkinson's disease; Huntington's disease; dementia, for example Alzheimer's disease, multi-infarct dementia, AIDS-related dementia, and Fronto temperal Dementia; neurodegeneration associated with cerebral trauma; neurodegeneration associated with stroke, neurodegeneration associated with cerebral infarct; hypoglycemia-induced neurodegeneration; neurodegeneration associated with epileptic seizure; neurodegeneration associated with neurotoxin poisoning; and multi-system atrophy.

6. A method according to claim 4, wherein the neurodegenerative disorder or condition comprises neurodegeneration of medium spiny neurons in the mammal.

7. A method according to claim 5, wherein the neurodegenerative disorder or condition is Huntington's disease.

8. A method of treating a movement disorder selected from Huntington's disease and dyskinesia associated with dopamine agonist therapy in a mammal, which method comprises administering to said mammal an amount of a selective PDE10 inhibitor effective in inhibiting PDE10.

9. A method of treating a disorder selected from obsessive/compulsive disorder, Tourette's syndrome, and other tic disorders in a mammal, which method comprises administering to said mammal an amount of a selective PDE10 inhibitor effective in inhibiting PDE10.

FIG. 1

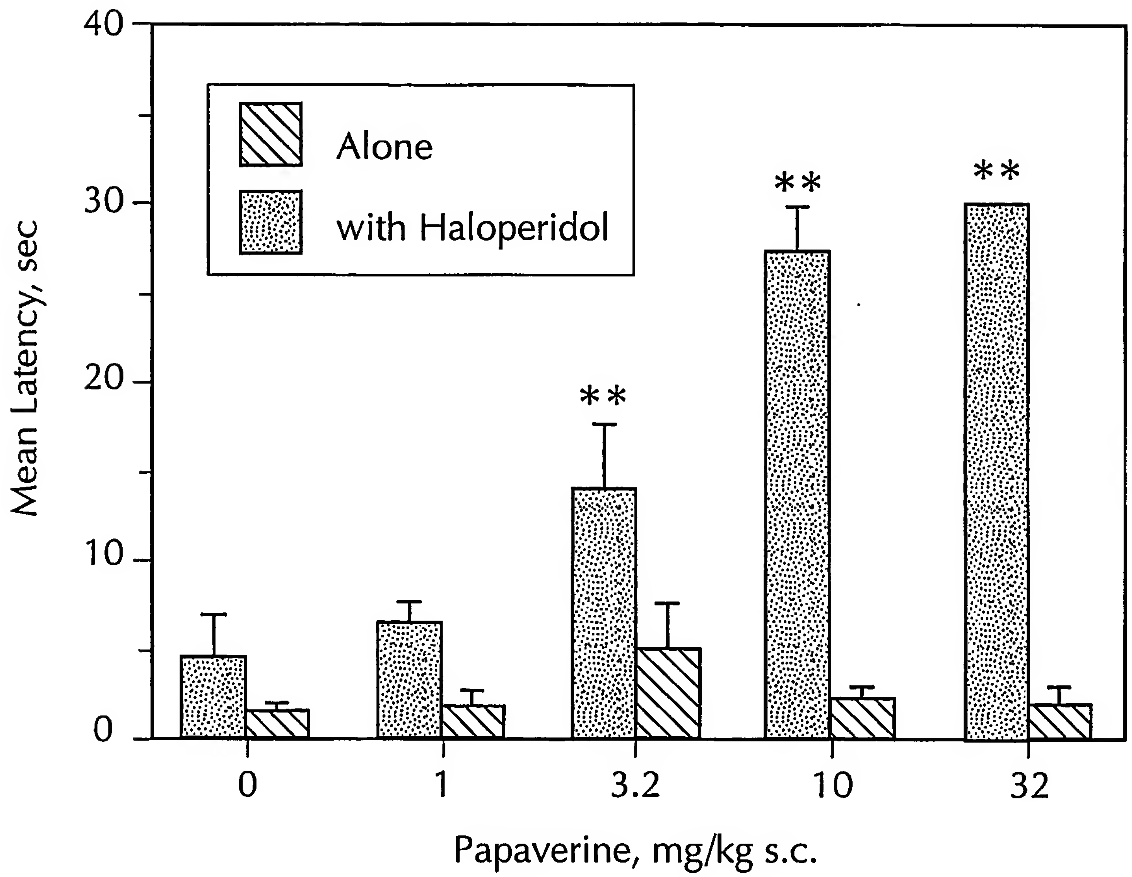

40
30
20
10
0
Mean Latency, sec
Alone
with Haloperidol
**
**
**
0
1
3.2
10
32
Papaverine, mg/kg s.c.

FIG. 2A

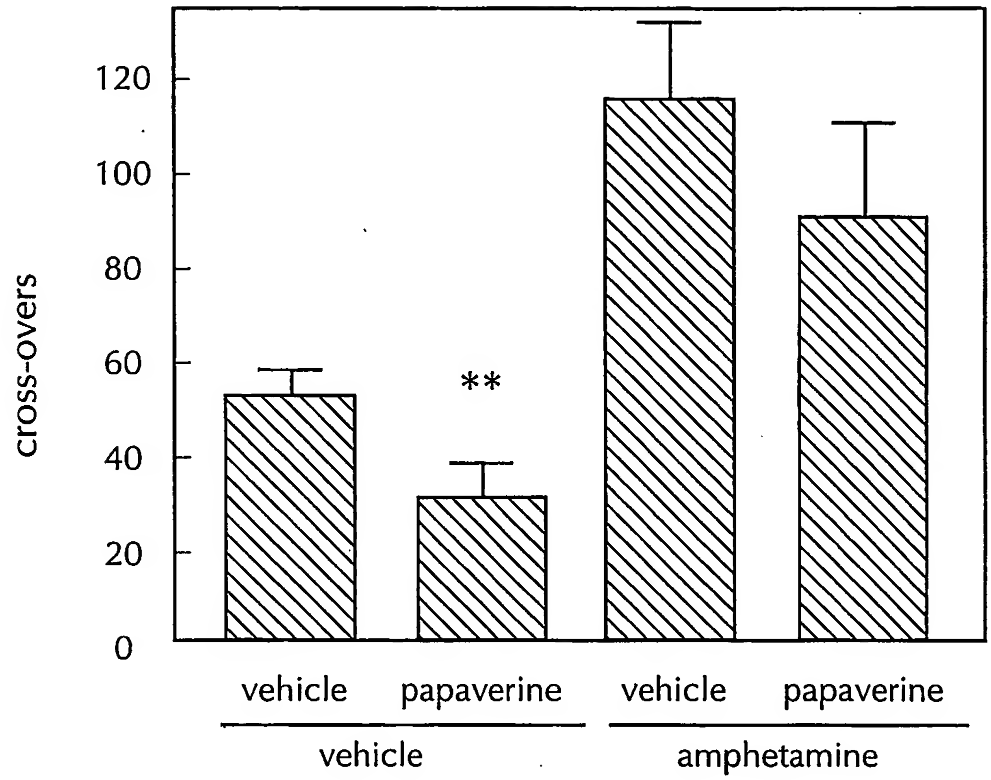

120
100
80
60
40
20
0
cross-overs
**
vehicle
papaverine
vehicle
papaverine
vehicle
amphetamine

FIG. 2B

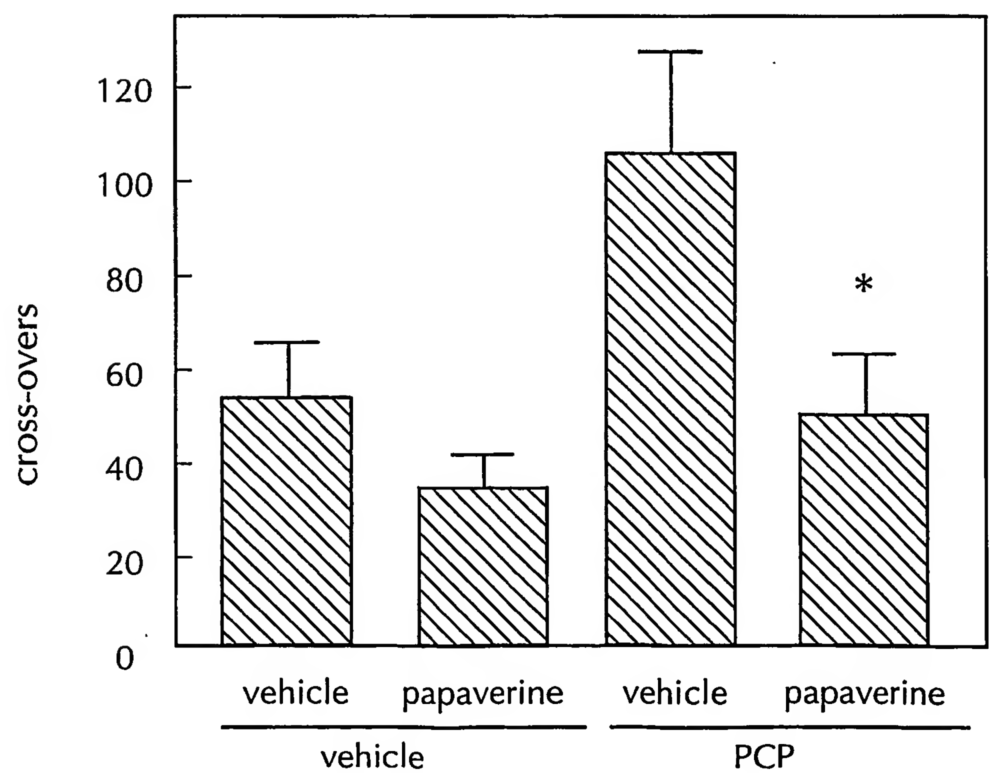

120
100
80
60
40
20
0
cross-overs
*
vehicle
papaverine
vehicle
papaverine
vehicle
PCP

FIG. 3

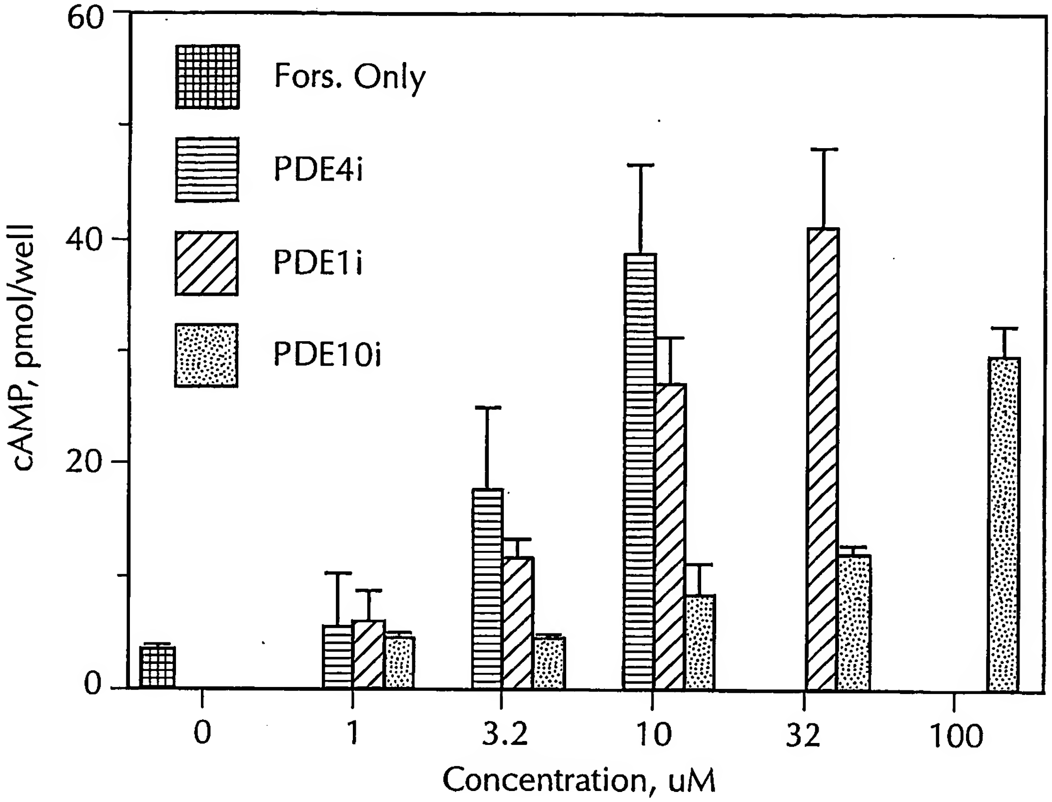

Fors. Only
PDE4i
PDE1i
PDE10i
cAMP, pmol/well
60
40
20
0
0
1
3.2
10
32
100
Concentration, uM

FIG. 4

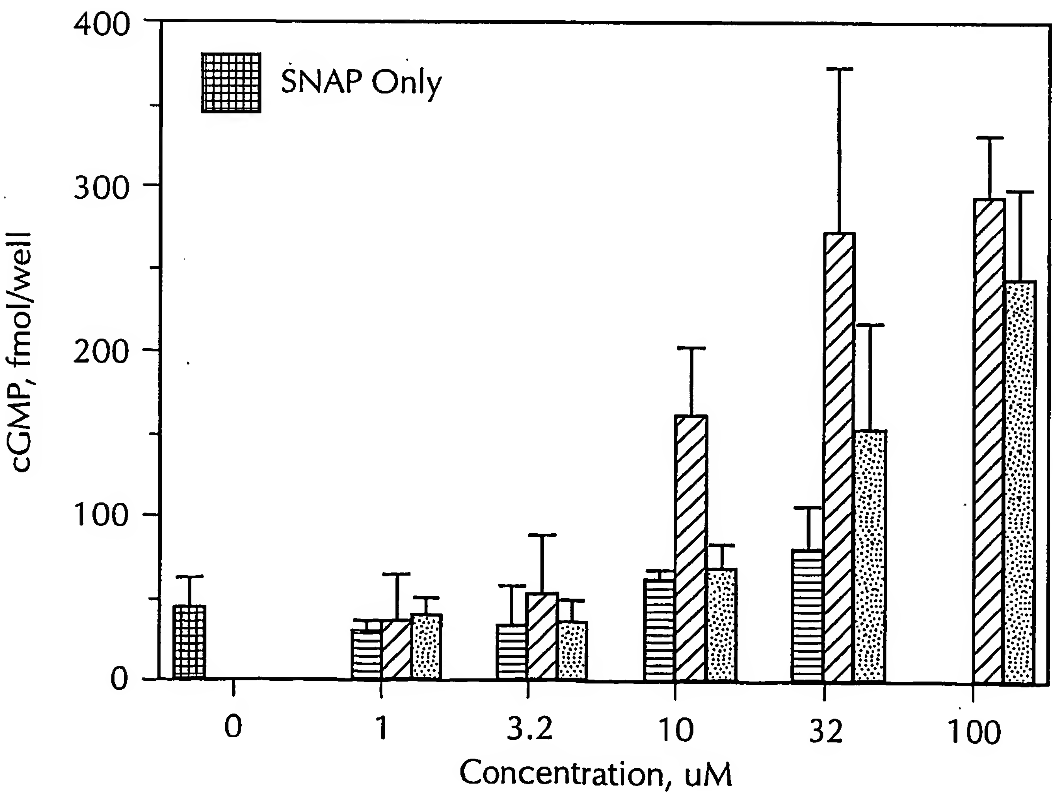

SNAP Only
cGMP, fmol/well
400
300
200
100
0
0
1
3.2
10
32
100
Concentration, uM

FIG. 5

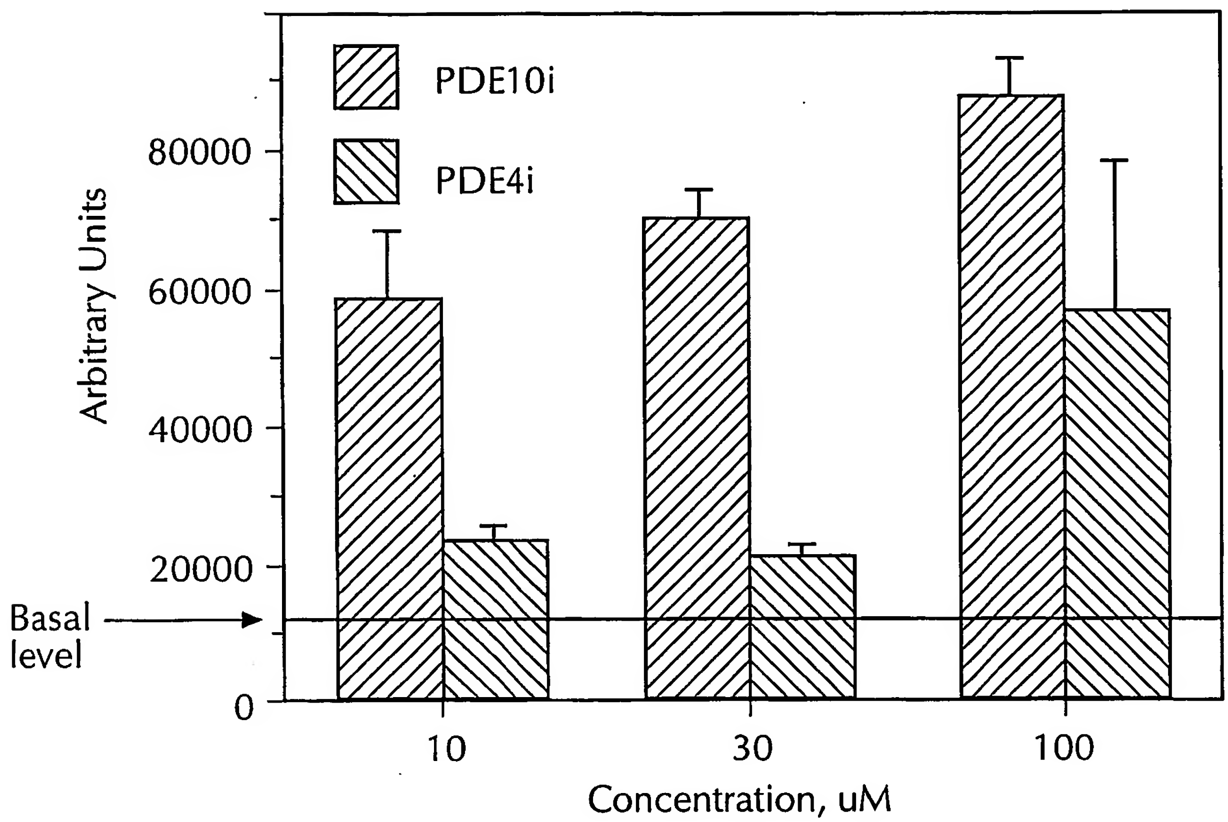
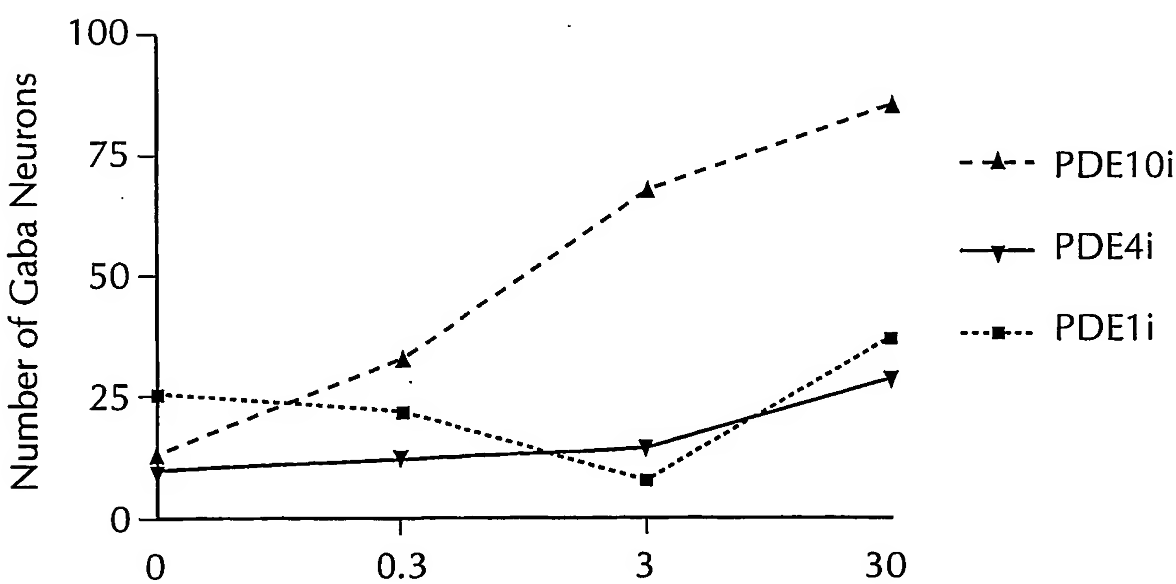

PDE10i
PDE4i
80000
60000
40000
20000
0
Arbitrary Units
Basal level
10
30
100
Concentration, uM

FIG. 6


100
75
50
25
0
Number of Gaba Neurons
0
0.3
3
30
PDE10i
PDE4i
PDE1i

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
13 November 2003 (13.11.2003)

PCT

(10) International Publication Number
WO 2003/093499 A3

(51) International Patent Classification[7]: C12Q 1/44, G01N 33/94, C12Q 1/68, G01N 33/68, 33/50, A61K 31/00, 31/472

(21) International Application Number: PCT/IB2003/001684

(22) International Filing Date: 22 April 2003 (22.04.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10/139,183 3 May 2002 (03.05.2002) US
10/177,018 20 June 2002 (20.06.2002) US

(71) Applicant (*for all designated States except US*): **PFIZER PRODUCTS INC.** [US/US]; Eastern Point Road, Groton, CT 06340 (US).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **LEBEL, Lorraine, Ann** [US/US]; Pfizer Global Research and Development, Eastern Point Road, Groton, CT 06340 (US). **MENNITI, Frank, Samuel** [US/US]; Pfizer Global Research and Development, Eastern Point Road, Groton, CT 06340 (US). **SCHMIDT, Christopher, Joseph** [US/US]; Pfizer Global Research and Development, Eastern Point Road, Groton, CT 06340 (US).

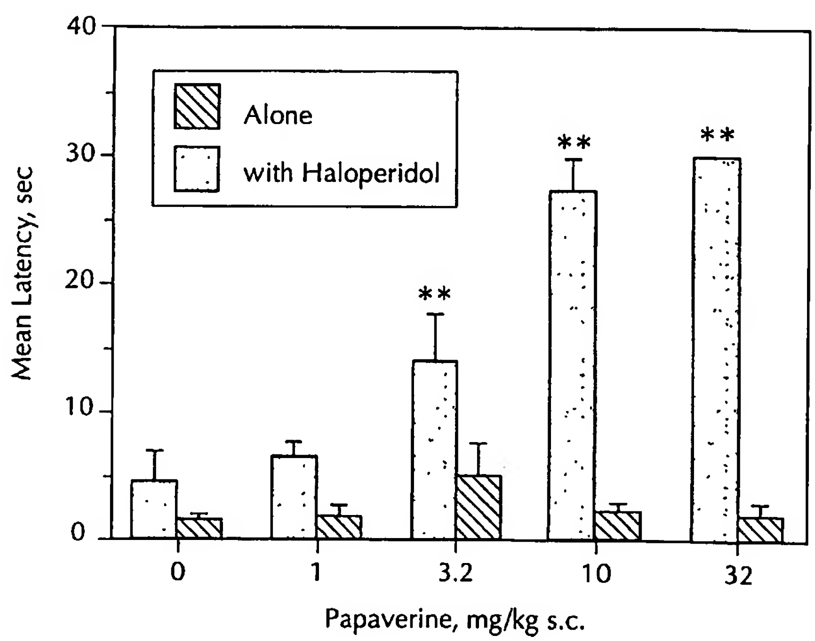
(74) Agent: **LUMB, J., Trevor**; Pfizer Inc., 201 Tabor Road, Morris Plains, NJ 07950 (US).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE,

[Continued on next page]

(54) Title: THERAPEUTIC USE OF SELECTIVE PDE10 INHIBITORS



(57) **Abstract:** The invention provides a method for treating certain neurologic and psychiatric disorders in mammals, including humans, comprising administration of a selective PDE10 inhibitor. In particular, the invention relates to treatment of mood, movement, and anxiety disorders; psychosis; drug, for example alcohol, addiction; disorders having as a symptom deficient cognition; and neurodegenerative disorders and conditions. The invention furthermore provides the use of papaverine as a selective inhibitor of PDE10. The invention also provides assays for identifying chemical compounds that have activity as selective PDE10 inhibitors.

WO 2003/093499 A3

ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

(88) Date of publication of the international search report: 22 April 2004

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IB 03/01684

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 C12Q1/44 G01N33/94 C12Q1/68 G01N33/68 G01N33/50
A61K31/00 A61K31/472

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01N A61K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, BIOSIS, PAJ, WPI Data, EMBASE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X A	DATABASE BIOSIS [Online] BIOSCIENCES INFORMATION SERVICE, PHILADELPHIA, PA, US; 2002, KLEIMAN R J ET AL: "PDE10 REGULATION OF INTRACELLULAR SIGNALING IN STRIATAL MEDIUM SPINY NEURONS IN CULTURE." XP002259393 Database accession no. PREV200300268363 abstract & SOCIETY FOR NEUROSCIENCE ABSTRACT VIEWER AND ITINERARY PLANNER, vol. 2002, 2002, page Abstract No. 43.18, 32nd Annual Meeting of the Society for Neuroscience;Orlando, Florida, USA; November 02-07, 2002 ----- -/--	1 2

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 October 2003	04 02 2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Vadot-Van Geldre, E

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	EP 1 281 771 A (PFIZER PROD INC) 5 February 2003 (2003-02-05)	1
A	paragraphs [0050], [0051], [0057]	2
X	FUJISHIGE K ET AL: "STRIATUM- AND TESTIS-SPECIFIC PHOSPHODIESTERASE PDE10A ISOLATION AND CHARACTERIZATION OF A RAT PDE10A" EUROPEAN JOURNAL OF BIOCHEMISTRY, BERLIN, DE, vol. 266, no. 3, December 1999 (1999-12), pages 1118-1127, XP000998326 ISSN: 0014-2956	1
A	abstract page 1118; table 1	2
X	SEEGER T F ET AL: "PDE10A MRNA IN SITU HYBRIDIZATION MAPPING IN THE RODENT BRAIN: APPARENT CO-LOCALIZATION WITH DOPAMINOCEPTIVE NEURONS" SOCIETY FOR NEUROSCIENCE ABSTRACTS, SOCIETY FOR NEUROSCIENCE, US, vol. 26, no. 1/2, 2000, page 921, XP000998405 ISSN: 0190-5295	1
A	abstract	2
A	DE 32 24 100 A (LONG MICHAEL) 29 December 1983 (1983-12-29) page 4, lines 1-5; claims 1,15 page 9, lines 23-29 page 14, line 24 - page 15, line 8 page 5, line 15 - page 6, line 22 page 7, lines 1-4 page 8, lines 16-25	1,2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 03/01684

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-2

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-2

   method for determining whether a chemical compound has activity in selectively inhibiting PDE10

   ---

2. claims: Claims 3-9

   the treatment of diseases associated with the central nervous system by the use of selective PDE10 inhibitors.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/IB 03/01684

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 1281771	A	05-02-2003	CA	2391117	A1	31-01-2003
			EP	1281771	A2	05-02-2003
			JP	2003135079	A	13-05-2003
			US	2003096323	A1	22-05-2003
DE 3224100	A	29-12-1983	DE	3224100	A1	29-12-1983